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Contributed paper

A novel precision bender system for focusing mirrors

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A novel mirror bender system utilizing cam-shaft mover (CSM) with 100 μm eccentricity was designed and successfully tested. The system was initially tested and characterized in the laboratory, and then later the performance was verified using the Advanced Photon Source synchrotron radiation source. The force from the two separate CSMs is translated to both ends of a mirror through a small-diameter bellows feed-through. The system uses an internal spring assembly to compensate for atmospheric pressure. A compact gear box with 10:1 ratio between the stepper motor and cam shaft is used to increase the precision of the bender system. This bender system is equipped with a precise rotary potentiometer and load cell for feedback. A system resolution better than 0.2 μm per step was achieved. This bender system was designed as a separate unit, is very compact and can be used to bend a mirror in both the vertical and horizontal planes. Details of the system design, changes made from the prototype system to the production unit and test results are presented here.

1. Introduction

The precision mirror bender system was designed for the Sector 12 beamline at the Advanced Photon Source located at the Argonne National Laboratory as part of a beamline upgrade. For this upgrade, four medium-sized 600-mm-long mirrors will be installed. The specified bending radius is large, from 600 m to infinity, and so the deformation on the mirror end, even for the smallest radius, is required to be less than 100 microns. The required precision of the bending system is 0.2 μm or less. A view of the typical mirror chamber is shown in figure 1.

Cam-shaft movers (CSM) were successfully used for the precise installation and beam-based alignment of the undulator cells for the linac coherent light source (LCLS) project (White *et al.* 2006). Therefore, a similar technique was used in the design of the precision mirror bender system for Sector 12. One of the major advantages of this system design is that, owing to the small eccentricity, the system will stay in the same position even in the event of a system power loss.

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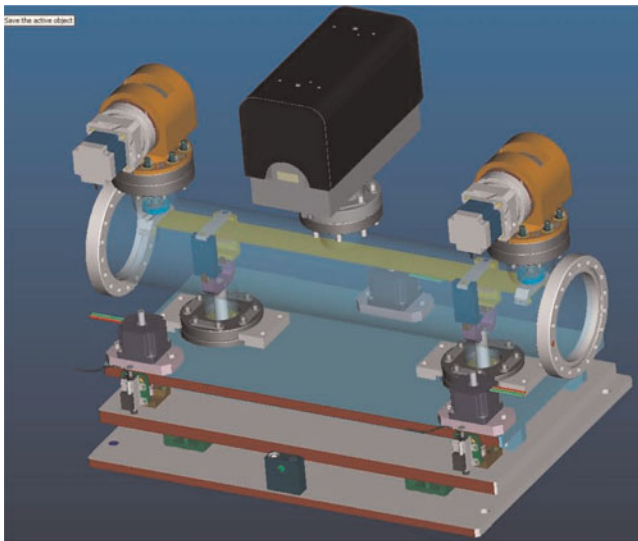


FIGURE 1. Mirror chamber with two mirror benders.

2. CSM design

A model of the CSM system is shown in figure 2. The housing (1) is made of 6063-T5 aluminium alloy and holds the cam shaft (2) with two ball bearings. Ball bearing (3) has a heat-treated crown and translates the eccentricity of the cam shaft into linear motion. The axis of ball bearing (3) on the left-hand side is offset 100 microns from the centreline of the shaft. A compact planetary gearbox with a

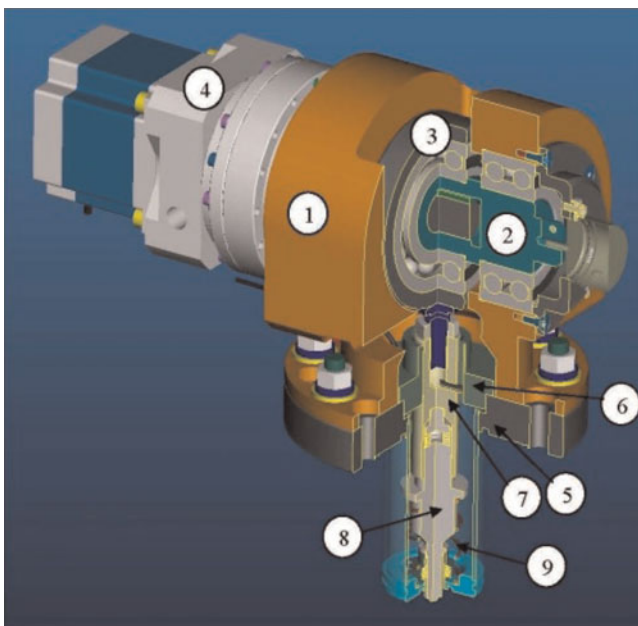


FIGURE 2. CSM system model.

10:1 ratio (4) with a hollow shaft output is attached to the left side of the housing (1) and has a shaft with a keyway. A NEMA 23-sized stepper motor is connected to the input end of the gear box. A ConFlat flange (5) is attached to the bottom of the housing with a bushing (6) that holds a guided piston consisting of two parts (7 and 8), and a small-diameter bellows separates the atmosphere from vacuum. The top portion of the piston has a screw for precise height adjustment. In the joint between the upper and lower parts of the piston, a miniature load cell is installed to control the force and correspondingly (after calibration) the mirror end displacement.

On the right-hand side of the cam shaft, a miniature rotary potentiometer is attached to calibrate the CSM and to locate the upper and lower extreme positions on the cam shaft. The entire CSM system can easily be attached to the vertical or horizontal end flanges on the mirror chamber (see figure 1), and therefore it can be used equally to bend mirrors in the vertical or horizontal planes. The distance between the mirror support points are 400 mm, and the distance between the piston ends on both sides of the mirror is 560 mm. Calculations have shown that the maximum force for the smallest bending radius and the thickest mirror will not exceed 100 Kg.

3. Initial testing

Initially, the first unit was fabricated to test the system's performance. The CSM was pre-loaded through the top opening by a 100 Kg force, and the position during rotation was measured using a Keyence[®] LK-G37 confocal laser displacement sensor with a resolution and repeatability of 0.05 μm . With the 10:1 gear box and a maximum of 400 steps per revolution of the stepper motor, the CSM provides a 0.09° minimum angular displacement per motor step. The LK-G37 software package was used to record approximately 11 000 data points during a single 360° revolution. The software was programmed to deliver a 1800° displacement over a time interval of 10 s. It is important to set the mover to a high number of revolutions so that the shaft rotates at a constant angular velocity. The data recorded consisted of the angular displacement of the cam and the linear displacement as measured by the LK-G37 sensor. The linear regions of the reciprocating motion of the cam were identified, curve fitted to an R value of approximately 1, and then the minimum displacement per step (microns per 0.09°) value was determined. The non-linear regions of the sine wave are ignored, but the ascending and descending linear regions are utilized to determine the minimum displacement per step values. An example of a typical test result is shown in figure 3. The step resolution was better than 0.2 μm .

4. Discussion

The main source of error in these experiments is the build-up of nonlinear backlash in the system which is nonlinear and varies at different cam positions. Additional sources of error in the experiment are the time lag of computer data-acquisition system and starting and stopping of the mover. Controlling the system from the output shaft would directly eliminate all backlash effects in the control. Consequently, after these initial tests were performed, a miniature rotary potentiometer was added to the output shaft as shown in figure 2. Also, tighter tolerances for the ball-bearing diameters in the housing and cam shaft were specified.

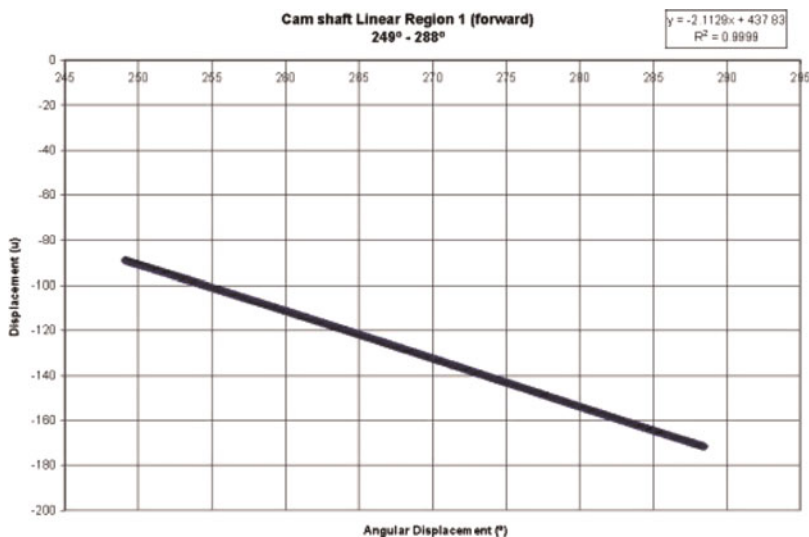


FIGURE 3. CSM linear region.

A final test of the fully assembled CSM system with the mirror attached was conducted on the actual beamline using synchrotron radiation. The precision of the CSM was confirmed; however, with this design it was impossible to keep the mirror flat due to atmospheric pressure forces. Even through the small bellows, a pressure force of about 8 Kg at each end of the mirror was imposed due enough to cause a small deflection in the mirror. Consequently, in the final design, a bellows with a 2.7 times smaller diameter was installed and a compression spring (9) (see figure 2) was also added to compensate for the ~ 1 Kg atmospheric pressure force.

5. Conclusion

Eight CSM systems were produced and installed; six to bend mirrors in the vertical plane and two for horizontal plane bending. The mirror chambers should be installed on the beamline within a short span of time.

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